RESEARCH DEPARTMENT

THE DESIGN OF LENS HOODS

Report No. T-089

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THE BRITISH BROADCASTING CORPORATION
ENGINEERING DIVISION

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SUMMARY

The factors which control the performance of a lens hood are discussed. A distinction is made between two degrees of protection given against unwanted light sources. Some numerical results are given which apply to the image orthicon television camera.

1. INTRODUCTION

The definition of veiling-glare index given by Hacking in his report on Secondary Flare in Lenses[1] and used in the B.B.C. lens specification[2] relates to a peak white level of illumination filling, but not exceeding the working field of view. This is unlikely to be true in any practical situation, but the assumption has been made that it is possible to use lens hoods which are efficient in preventing extraneous non-image-forming light from reaching the lens. The extent to which it is practicable to do this has been investigated and forms the subject of this report. Many lens hoods which are sold with photographic cameras are almost useless and it is not surprising that the value of lens hoods has been questioned by some enthusiastic amateurs.

2. BASIC CONSIDERATIONS

2.1 Length of Hood

In Fig. 1, OX represents the optical axis of a lens and AB is the entrance pupil.* Rays from a point on the periphery of the field of view are inclined at an angle θ to the optical axis: three such rays are shown as AC, OD, BE. It is assumed that the object point is sufficiently distant that the three rays are nearly parallel. A section of lens hood is shown as LMF. A ray of light BF inclined at an angle ϕ to the optical axis will just touch the entrance pupil: this represents the limiting case because light from any source inclined at an angle greater than ϕ will not reach the entrance pupil AB. The locus of extreme positions of the aperture of the hood is given by the line AC, because the lens hood must cause no vignetting.

*Entrance pupil is defined as the image of the iris as seen through those components of the lens in front of the iris.

Let AB = d (diameter of entrance pupil)
LM = l (length of hood)

Then it can easily be shown that

$$l = d/(\tan\phi - \tan\theta) \tag{1}$$

This expression gives the length of hood (measured from the plane of the entrance pupil) which is required for protection from a source inclined at an angle ϕ. Fig. 1 shows that as the point F moves along AC in the direction of C, the angle ϕ will diminish, i.e. the longer the hood, the better the protection.

2.2 Partial and Complete Protection

The protection given by a hood is not complete if non-image forming light reaches any part of the front element of the lens. Nevertheless, if the shadow cast by a lens hood from the offending light source just includes the whole of the entrance pupil (as represented by the area BFL in Fig. 1), then there is a very substantial reduction in the non-image-forming light which can be scattered in such a direction as to pass through the iris and finally reach the image. This condition is referred to as partial protection.

For a lens operating at full aperture, the distinction between complete protection of the front element and shadowing of the entrance pupil becomes somewhat academic (although the plane of the entrance pupil will certainly not coincide with

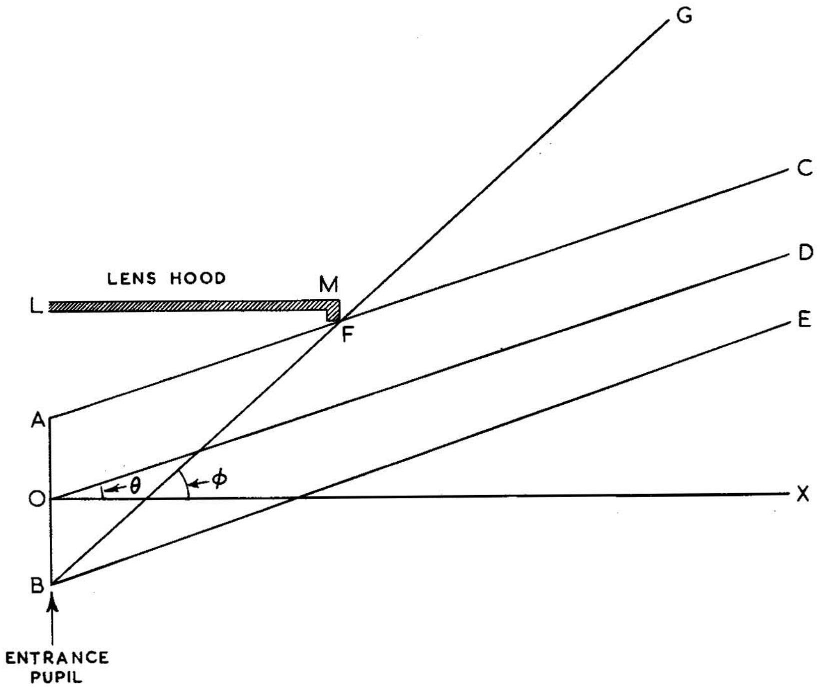

Fig. 1 - The action of a lens hood

OX optical axis
AC, OD, BE rays from object
AB entrance pupil
GFB ray from light source
LMF lens hood

any part of the outside surface of the front element). Equation (1) gives the conditions for complete protection if d is the diameter of the front element and l is measured from the front element.

2.3 Shape of Lens Hood

The optimum shape of the front aperture of a lens hood is in general a rectangle with radiused corners. The reason for this will be appreciated if the envelope of all the image-forming rays leaving the scene (which can be idealized as a rectangle perpendicular to the optical axis) and reaching the circular entrance pupil of the lens is considered. In its two extreme conditions we have a circle and a rectangle: at all intermediate planes we have a combination of these two shapes, namely a rectangle with modified corners which are arcs of a circle. In designing lens hoods to work with television cameras, a considerable variation in the focal lengths is encountered. For example, an image orthicon may be used with a 2 in (51 mm) lens and a 40 in (1016 mm) lens. The physical length of the hood considered as a multiple of the focal length is one of the factors which controls the shape of the aperture in the lens hood; the other factor is the angular field. Two specific examples may be helpful. For a 2 in (51 mm) lens operating at f/4 and a hood giving partial protection from a light source immediately above the centre of the field and inclined at an angle of 17°, reference to Fig. 2 shows that a hood of about 7½ in (191 mm) length is required. A simple calculation shows that the front aperture of such a hood will be 4·1 in by 5·3 in (104 mm by 135 mm) with circular corners of radius 0·25 in (6·35 mm) (the radius of the entrance pupil). In this case the front aperture is almost of rectangular shape. On the other hand, if we consider a 40 in

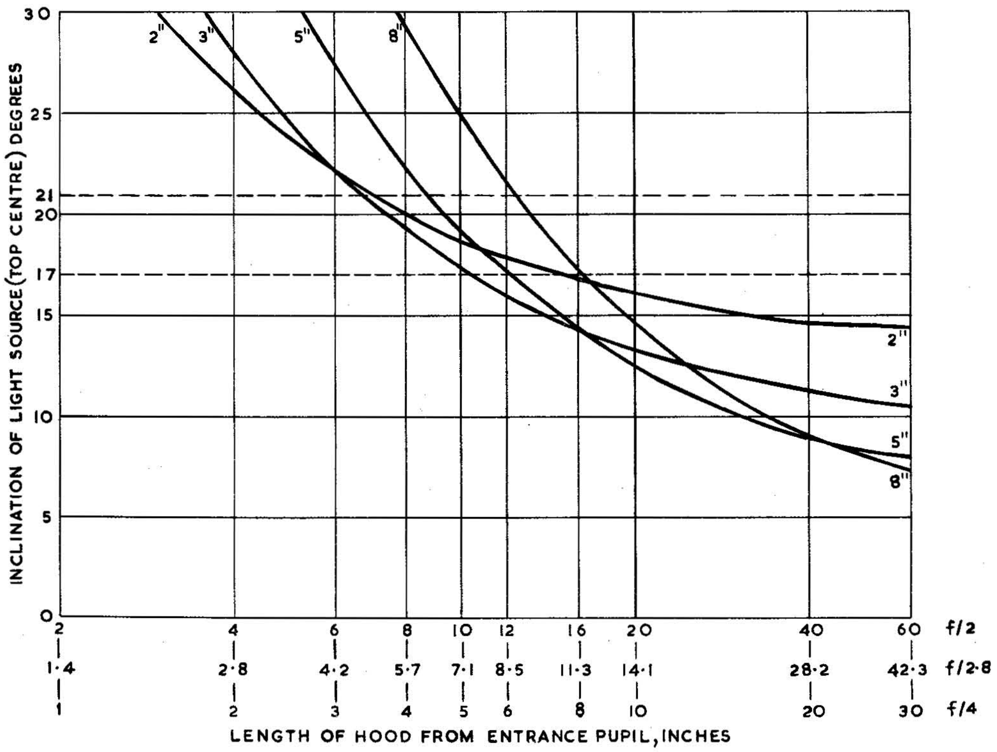

Fig. 2 - Rectangular lens hoods for 2 in - 8 in lenses at apertures of f/2, f/2·8 and f/4 (Image size 0·96 in by 1·28 in)

(1016 mm) f/8 lens, a hood of length 9·6 in (244 mm) will protect the lens from a light source above the centre of the field inclined at an angle of 28°. The shape of the front aperture is now almost circular. The rectangle has dimensions 5·23 in by 5·31 in (133 mm by 135 mm) and the radius of curvature of the rounded corners is 2½ in (64 mm).

The above two examples are perhaps somewhat extreme cases but they show that somewhere in the range of focal lengths between 2 in (51 mm) and 40 in (1016 mm) (and for hoods of the order of 10 in (254 mm) long) the shape of the front aperture of the hood changes from almost rectangular to almost circular. In specifying hoods* for the image orthicon camera it has been decided to fit lenses with focal lengths up to and including 8 in (203 mm) with hoods with a rectangular aperture but for focal lengths of 12 in (305 mm) and greater a circular aperture is a sufficiently good approximation to the optimum shape for most practical purposes.

3. PROTECTION ANGLES

In the two examples just quoted, arbitrary protection angles were given without any explanation. If each lens was used in isolation (not mounted on a lens turret) and there were no restrictions on the length of lens hood, then it would be possible to shield the entrance pupil from light sources that were only just outside the field of view. The graphs given in Fig. 2 show that a law of diminishing returns operates in the sense that for each extra (angular) degree of protection, the increments in length increase rapidly. As an example, we may note that the top centre of the field of a 2 in (51 mm) lens (image orthicon field) subtends an angle of about 13° 30′ (arctan 0·24) and for protection against light sources at 20°, 18°, 16°, 14° we find from equation (1) (or Fig. 2) that lengths of hood for an aperture of f/4 are 4, 5·9, 10·7 and 53·6 in (102, 150, 272 and 1361 mm) respectively. Alternatively we may observe that on differentiating equation (1), we have

$$\frac{dl}{d\phi} = -d\,\frac{\cos^2\theta}{\sin^2(\theta-\phi)} \tag{2}$$

The modulus of this function increases very rapidly as ϕ tends towards θ.

Because a hood 53·6 in (1361 mm) long would be very inconvenient to use (its front aperture would be about 26½ in by 35 in (673 mm by 889 mm)) and difficult to make with sufficient stability** for a reasonable weight, clearly a compromise must be sought. In actual fact, turret working is almost invariably used with television cameras*** so that maximum length of hood is restricted because of the necessity of avoiding interference between the field of the lens in use and any parts of the mounts (including hoods) of the other lenses on the turret. However, the above considerations show that even if turret working was not usual, it would be necessary to restrict the angle of protection.

*B.B.C. Specification TV88/2.

**If the front aperture of the hood is not accurately positioned, an image of the hood is formed which is substantially in focus.

***Except when the television camera uses a zoom lens.

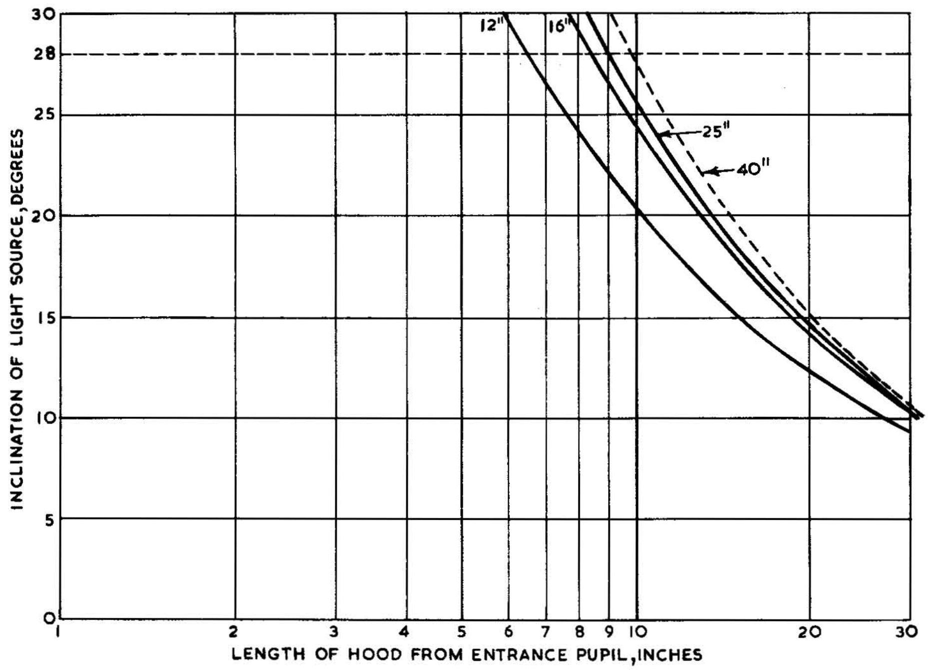

Fig. 3 - Conical lens hoods for 12 in - 40 in lenses relative apertures not constant 12 in f/4, 16 in f/4, 25 in f/5·6 and 40 in f/8 (Image size 0·96 in by 1·28 in)

Detailed design considerations relating to one specific camera would be inappropriate in this report but it may be of general interest to state that the latest versions of the image orthicon television camera use a turret of diameter such that it is possible to protect the lenses in the 2 in (51 mm) to 8 in (203 mm) range of focal lengths (aperture not exceeding f/4) for light sources inclined at an angle of 17° above the optical axis in a vertical plane. This gives rise to hoods which are in the range of lengths from 5½ in (140 mm) to 8½ in (216 mm) (see Fig. 2) and this can be done without causing any mutual interference of one lens with another. A comparison of the light shielding properties of conical and rectangular hoods of the same length is shown in Figs. 4a and 4b. This diagram also shows the nature of the protection in planes other than the vertical plane which includes the optical axis.

4. EFFECT OF UNUSUAL LENS DESIGN

The simple theory of hoods embodied in equation (1) will require considerable modification to suit telecentric* designs and those which are more than telecentric. One result can be the disappearance of the distinction between partial and complete protection. This happens when the stop is external to the lens. Another factor which must be considered is the changing position of the entrance pupil with field angle. If the lens hood protects the entrance pupil (in all its positions) from stray light then a condition of partial protection will have been achieved although the data plotted in Figs. 2 and 3 may not be applicable. If the front element is protected by the hood then there will be a condition of 'complete protection' whatever the design of the lens.

*A lens is said to be telecentric when either the entrance or exit pupil is located at infinity.

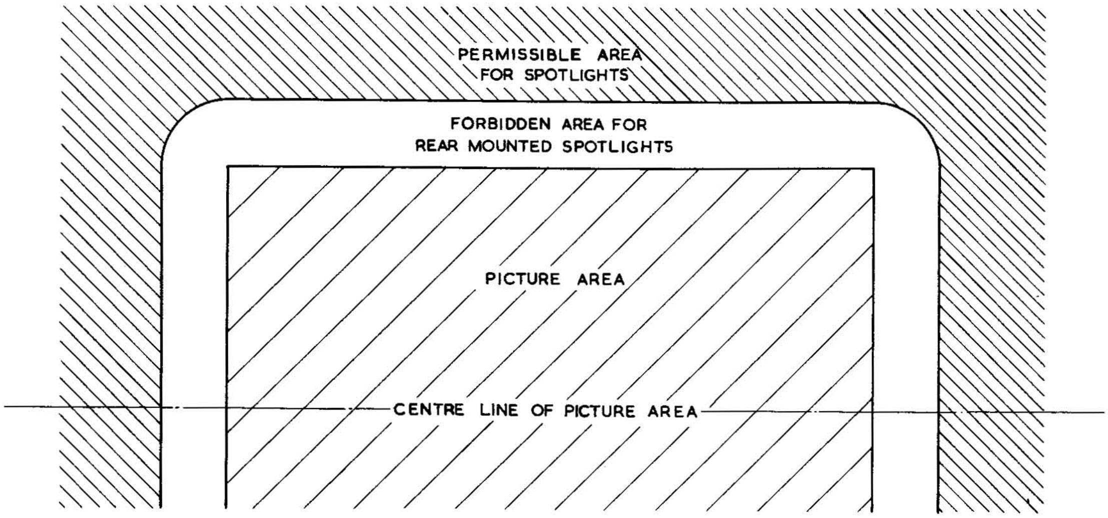

Fig. 4a - The effect of using a rectangular hood, 7½ in long, with a 2 in lens (1·6 in diagonal-image field)

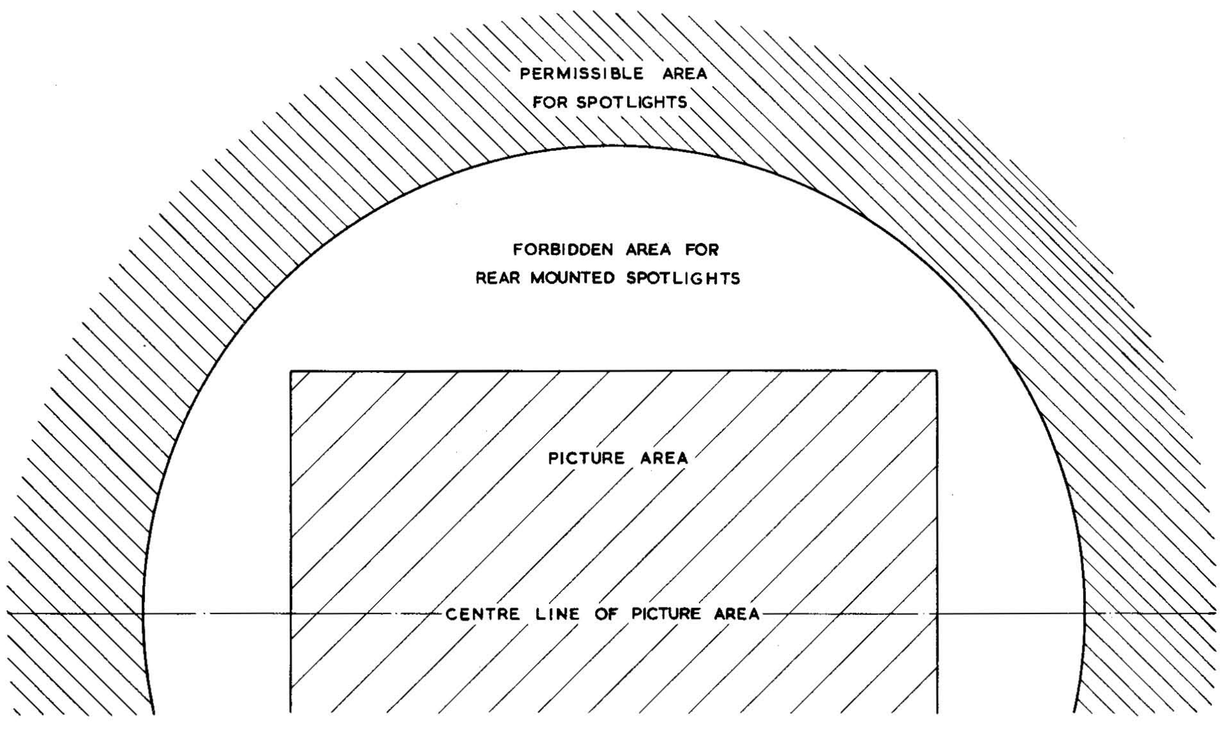

Fig. 4b - The effect of using a conical hood, 7½ in long, with a 2 in lens (1·6 in diagonal-image field)

5. CONCLUSIONS

1. For complete protection against light sources, no light from the sources in question must reach the front of the lens.

2. For a lens which is stopped down, a good measure of protection is achieved if the hood just prevents unwanted light from reaching the entrance pupil.

3. To be really effective, lens hoods have to be long. Mutual interference between several lenses mounted on a turret is the factor which usually limits the length of hood and thus the protection angle.

4. The optimum shape of a lens hood is rectangular with radiused corners. For television applications the optimum shape varies from almost rectangular to almost circular.

6. REFERENCES

1. "Secondary Flare in Optical Lenses", Research Department Report No. T-076, Serial No. 1960/21.

2. B.B.C. Specification for Television Lenses, TV88/2.

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